COMMISSIONING OF THE ATLAS LIQUID ARGON CALORIMETER

A. GIBSON*, on behalf of the ATLAS Liquid Argon Calorimeter Group

Department of Physics, University of Toronto,
60 Saint George Street,
Toronto, Ontario, M5S 1A7, Canada
**E-mail: adam.gibson@cern.ch*

The Liquid Argon (LAr) calorimeter provides electromagnetic and forward hadronic calorimetry for the ATLAS experiment at the LHC. Since the installation of the calorimeter in 2006, the electronic calibration and readout systems have been exercised with regular calibration and cosmic runs, and with three days of LHC single beam runs. These datasets have enabled detailed studies of calibration procedures, pulse shape models, uniformity of response, detector noise, and the possibility of noise and cosmic rays as backgrounds to jet and missing energy measurements. They have allowed a precise understanding of the detector behavior. The LAr calorimeter is well prepared for LHC collisions, which we hope for by the end of 2009.

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1. The ATLAS Liquid Argon Calorimeter

The ATLAS [1] liquid argon sampling calorimeters consist of three distinct technologies all of which use liquid argon as an ionization medium. The central and end-cap electromagnetic (EM) calorimeters use lead absorbers to achieve a minimum depth of 22 radiation lengths and are segmented into three longitudinal sampling layers along with a presampler layer. The hadronic end-cap uses copper absorbers to achieve a minimum depth of 10 interaction lengths, while the forward calorimeter uses copper and tungsten absorbers to extend the hermetic calorimeter coverage to η of 4.8. All of these systems are designed to cope with the high interaction rate and radiation doses at the Large Hadron Collider.

The finely segmented LAr calorimeter consists of 182,486 readout channels, and has been installed in the ATLAS cavern since 2006. Only 36 channels are permanently dead, less than 0.1% suffer from large noise, and about 1.2% have a broken readout component that can be repaired when access to the detector is next available[a].

The LAr [1] is read out by a system of front-end and back-end electronics that amplify, shape, and digitize the ionization signal and then reconstruct the deposited energy. A dedicated calibration board pulses the system, participating in campaigns of calibration runs including pedestal and noise measurements, measurements of the electronic gain, and characterizations of the pulse shape. Because of differences between the ionization and calibration pulses, the ionization pulse shapes must be predicted [2] and are then used with an optimal filtering method to reconstruct the energy and time of calorimeter deposits.

Regular electronic calibration runs and cosmic ray runs have been taken since the detector's installation was completed in 2006. Three days of LHC single beam data were recorded in September 2008 including massively energetic "splash" events where the proton beam was incident on a collimator upstream of ATLAS.

2. Noise and $E_{\mathrm{T}}^{\mathrm{miss}}$ Measurements

The electronic noise of the LAr calorimeter is regularly measured in calibration and cosmic runs, with the noise ranging from less than 10 MeV to more than 500 MeV per calorimeter cell, as expected. One impact of calorimeter noise is degraded $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution and fake $E_{\mathrm{T}}^{\mathrm{miss}}$. Using random triggers from a fifteen-hour cosmic ray run from 2009, we calculate $E_{\mathrm{T}}^{\mathrm{miss}}$ using just the LAr calorimeter, as shown in Fig. 1. Two $E_{\mathrm{T}}^{\mathrm{miss}}$ calculations are compared with expectations from a simple Gaussian noise model. The agreement is good. The calculation with topological clusters includes fewer cells and thus has lower $E_{\mathrm{T}}^{\mathrm{miss}}$ values. This same analysis, in an earlier run, highlighted a coherent noise problem which was subsequently traced to a bad high voltage (HV) cable and repaired.

3. Response Uniformity from Cosmic Rays as Minimum Ionizing Particles

Minimum ionizing cosmic rays leave a characteristic signal above noise in the LAr when they pass through the detector in a projective manner, passing close to the center of ATLAS. A study of 2008 cosmic ray events makes projectivity cuts based on tracks reconstructed in inner detector, and then

[a]The detector status is given as of September 26, 2009.

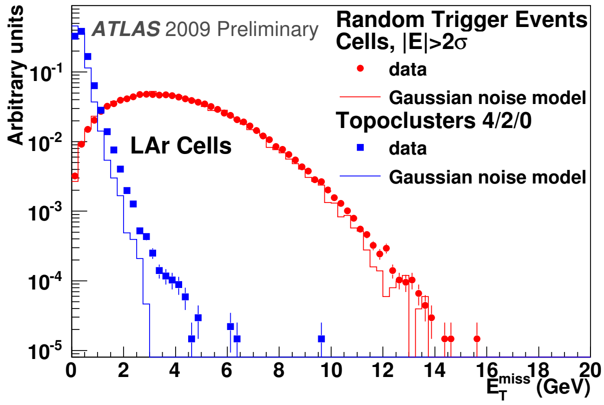

Fig. 1. Two $E_{\mathrm{T}}^{\mathrm{miss}}$ calculations are shown for random triggers from a cosmic run, along with expectations from a simple Gaussian noise model.

forms clusters of LAr cells. The cluster energy distribution is well fit by a Landau distribution convoluted with a Gaussian. The peak of the Landau distribution is shown as a function of η in Fig. 2, for clusters formed in the middle sampling layer. The deposited energy varies with the LAr geometry and is well modeled by cosmic Monte Carlo simulation (MC). After a 1% global scale correction the data and MC agree at the 1% level over the η range shown. This study gives us confidence in our signal reconstruction and calibration, our detector simulation, and the uniformity of calorimeter response.

4. Precision Pulse Shape Studies

Cosmic rays sometimes leave a large amount of energy in the ATLAS calorimeters, for example, from hard *bremsstrahlung* events. Large energy deposits were also seen in early LHC single beam runs, especially in the collimator “splash” events. These large energy deposits leave very clean ionization pulse shapes, allowing precise studies of the drift time and velocity and tests of our pulse shape models. Figure 3 shows one such digitized pulse from a 2008 cosmic run. Studies in “splash” events have shown a pulse shape accuracy of 1.8% in the middle sampling layer of the central EM calorimeter, while studies of cosmic events also confirm our knowledge of the ionization pulse shape.

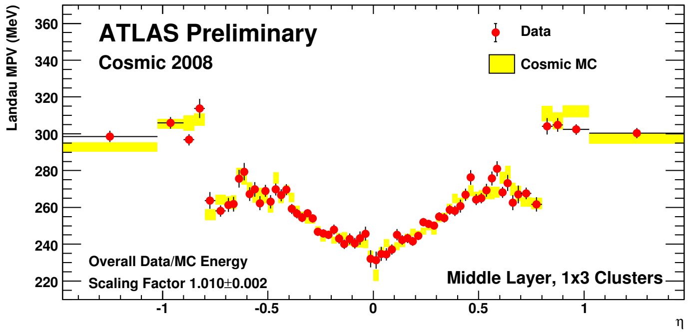

Fig. 2. The energy deposited vs. η by minimum ionizing cosmic ray muons in the middle sampling layer of the LAr. The most probable value (MPV) of a fitted Landau distribution is given for data and MC.

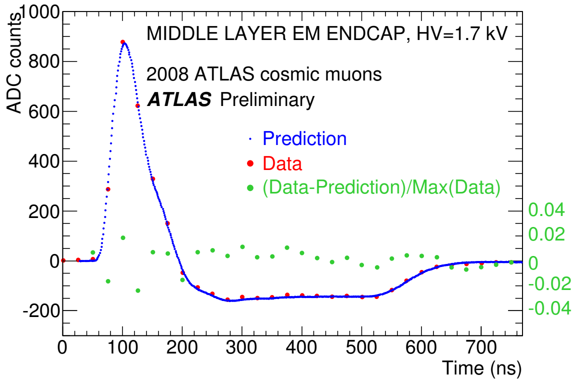

Fig. 3. Digitized pulse shape in a middle sampling layer cell from a high energy cosmic ray event. The prediction is shown as blue points (or a blue curve), the data as red points, and a comparison as green points which are close to zero throughout.

5. "Jets" and Electrons in Cosmic Ray Events

High energy deposits from cosmic rays reconstruct as "jets". These jets can be a non-negligible background for some physics measurements, e.g. searches for mono-jet production with a jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ signature, and have proven useful for preparing the LAr calorimeter and the combined ATLAS detector for physics measurements. Figure 4 shows the jet E_T distribution for one sixteen-hour cosmic ray run from September 2008. These cosmic rays differ in many respects from legitimate QCD jets and offer a number of possibilities for rejection. Two of these are illustrated in Figure 4. Cuts on the EM fraction and on the number of constituent calorimeter clusters, which have little effect on QCD jets, eliminate most of the jets from cosmic rays.

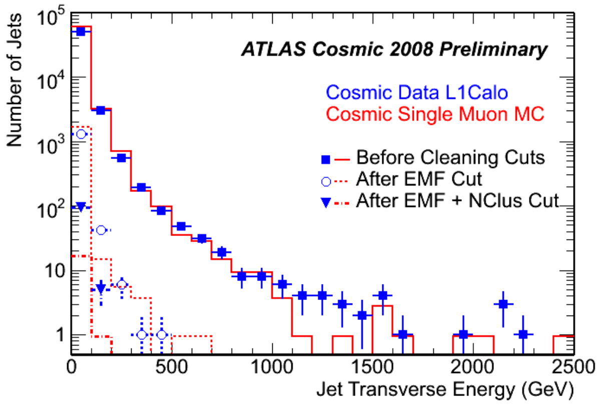

Fig. 4. Reconstructed jet E_T distribution from cosmic rays. The red lines are simulated cosmic ray muons, while the blue points are from data. The filled squares are before cleaning cuts, the white open circles after cutting jets with $0.2 <$ EM fraction < 0.97, and the filled triangle after also removing jets with fewer than seven calorimeter clusters.

In contrast to these fake jets, real ionization electrons have also been identified at ATLAS using the Transition Radiation Tracker and the LAr calorimeter [3].

Acknowledgments

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